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(54) **ARRAY SUBSTRATE FOR FLEXIBLE DISPLAY DEVICE AND METHOD OF MANUFACTURING THE ARRAY SUBSTRATE**

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H01L 33/52 (2010.01)
H01L 27/15 (2006.01)

(52) **U.S. Cl.**
CPC ***H01L 33/52*** (2013.01); ***H01L 27/15*** (2013.01)
USPC **438/33**; 438/34; 438/42; 438/462

(58) **Field of Classification Search**
USPC 438/33, 34, 42, 462
See application file for complete search history.

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(57) **ABSTRACT**

In an aspect, an array substrate for a flexible display device and a method of manufacturing the array substrate, the method including operations of arranging at least one lower protective film on which a plurality of display units that are covered by thin-film encapsulation (TFE) units are arrayed; performing half cutting and full cutting on the at least one lower protective film; and completing the manufacture of each of the plurality of display units by removing remaining parts on the at least one lower protective film from the half cutting and full cutting is provided.

17 Claims, 6 Drawing Sheets

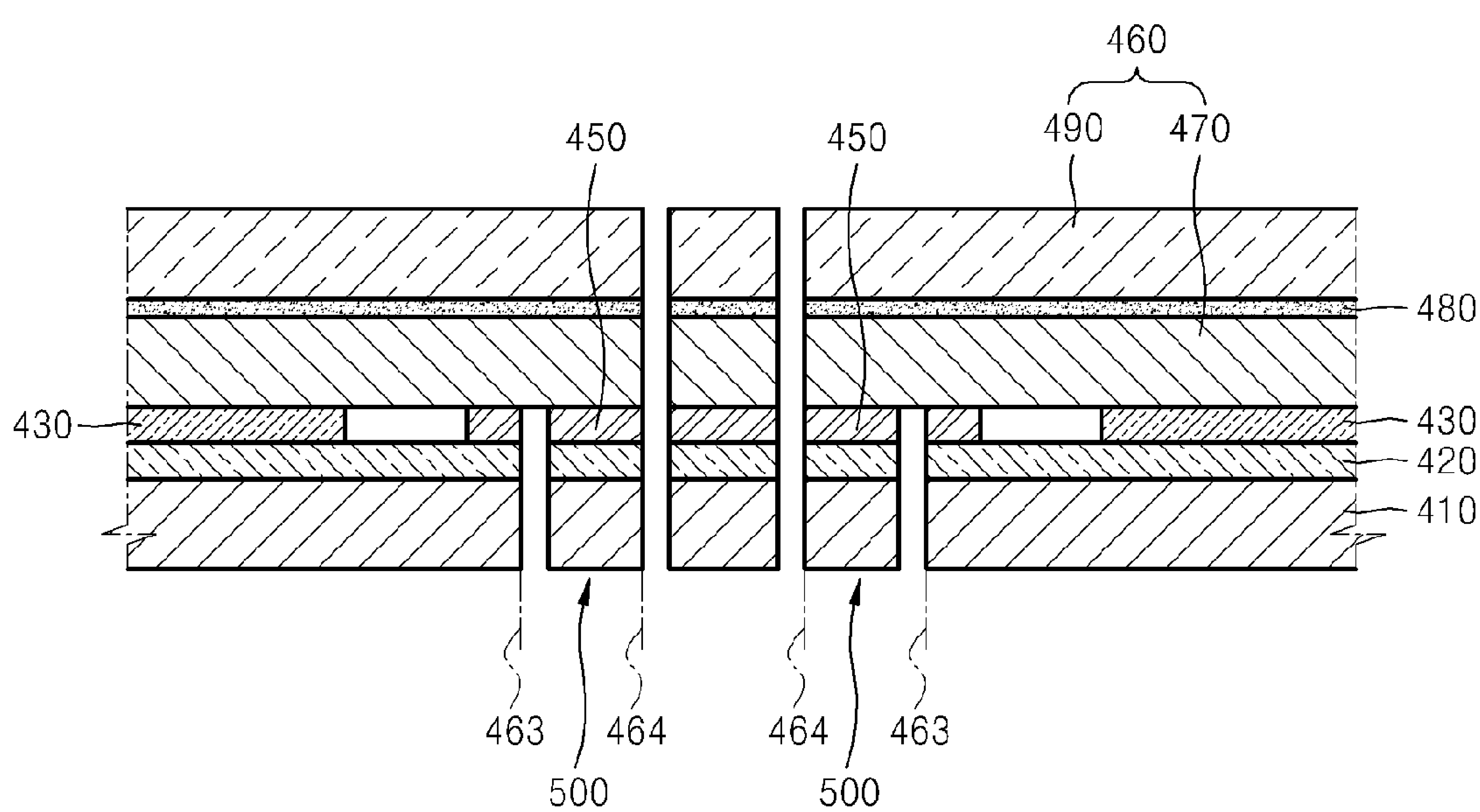


FIG. 1

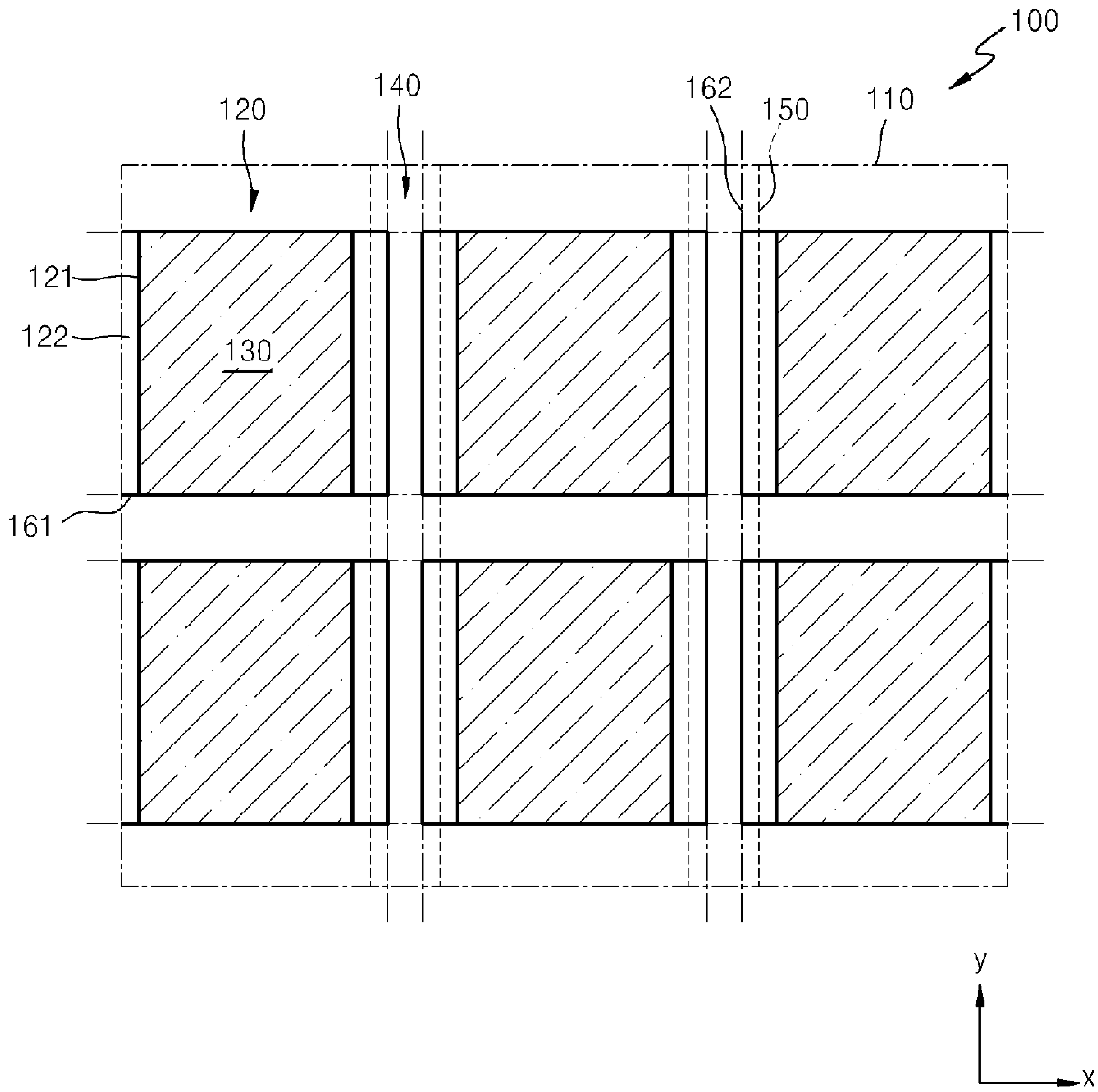
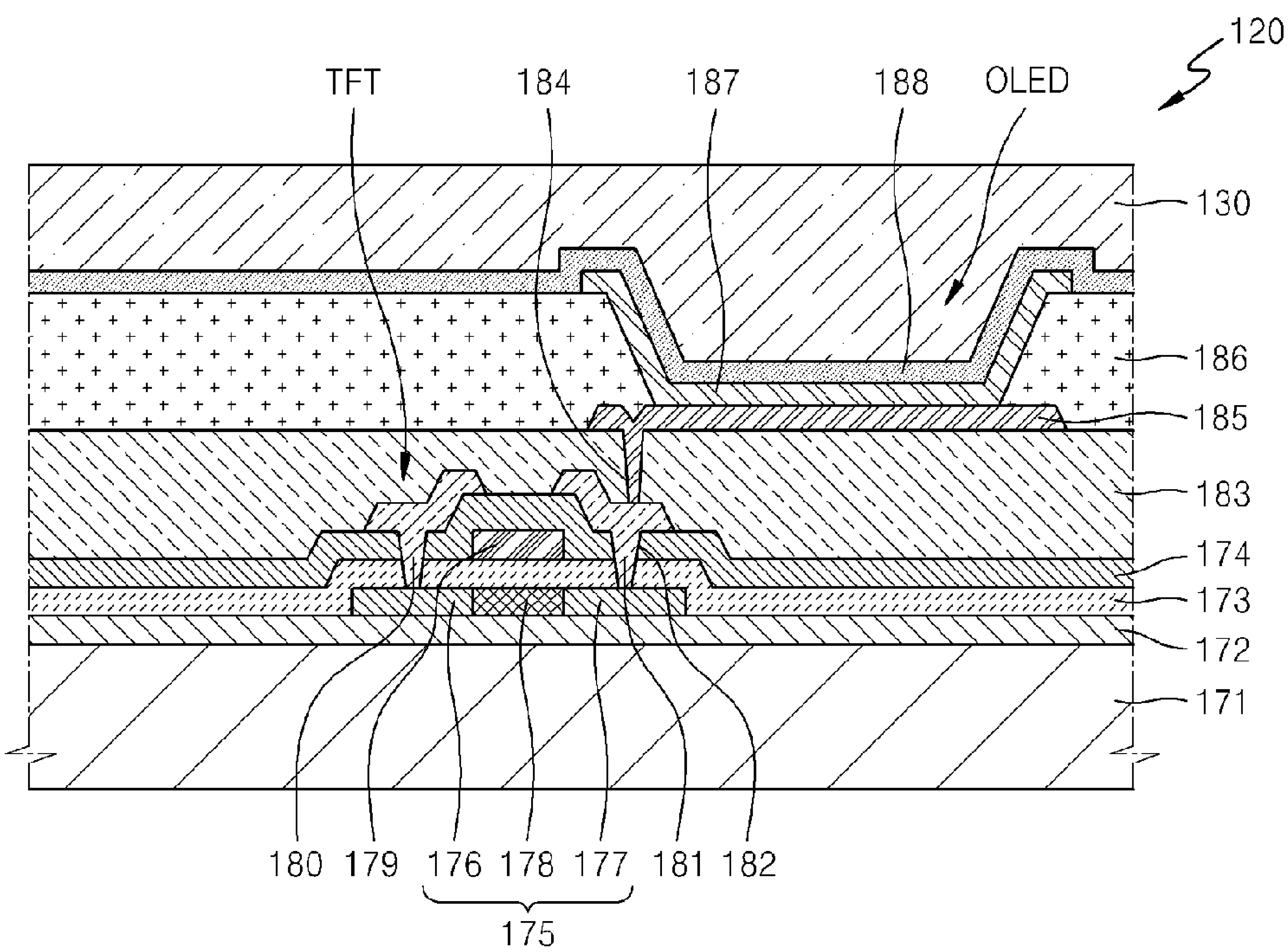
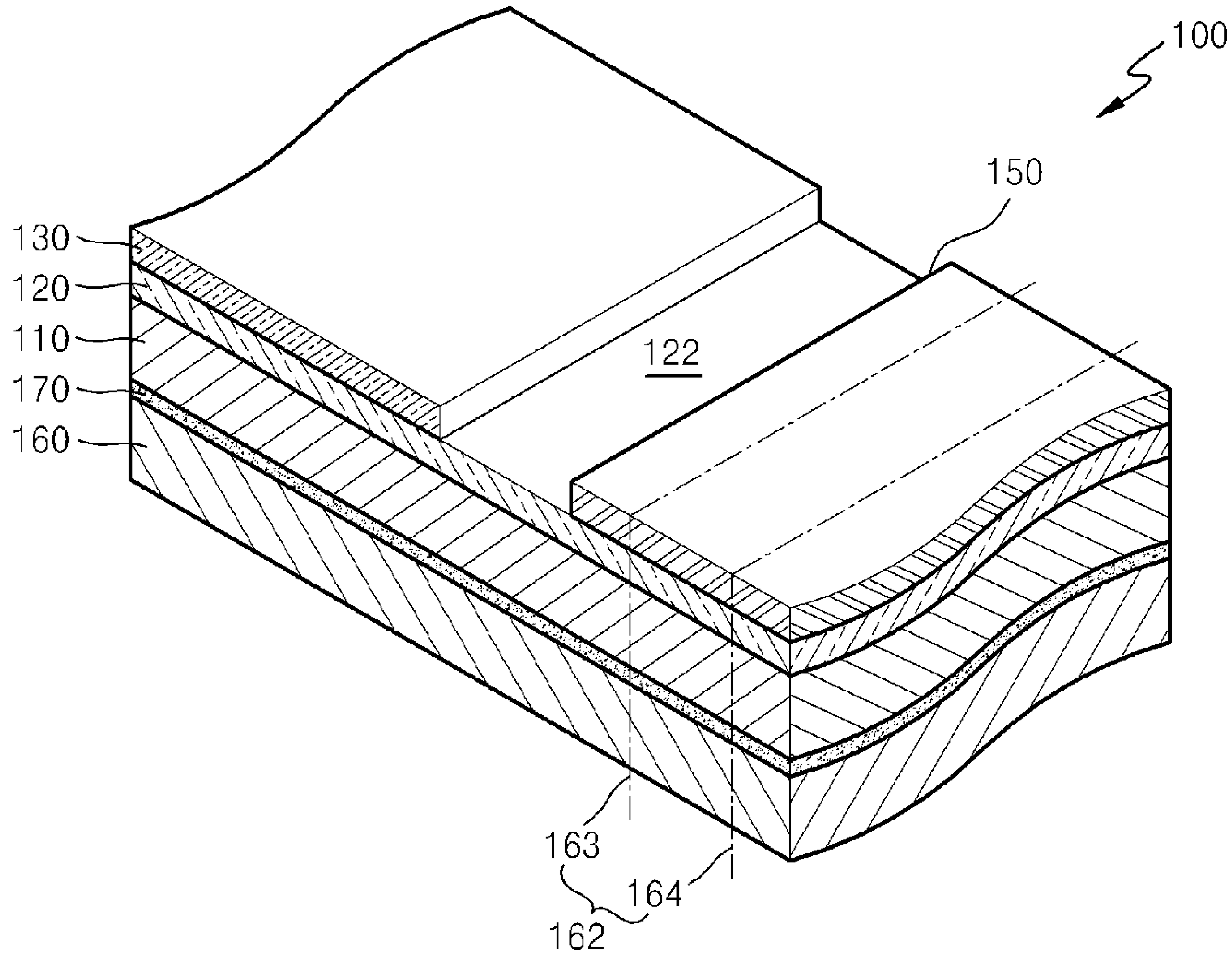


FIG. 2



120
TFT
184
187
188
OLED
130
186
185
183
174
173
172
171
180
179
176
178
177
181
182
175

FIG. 3A


100
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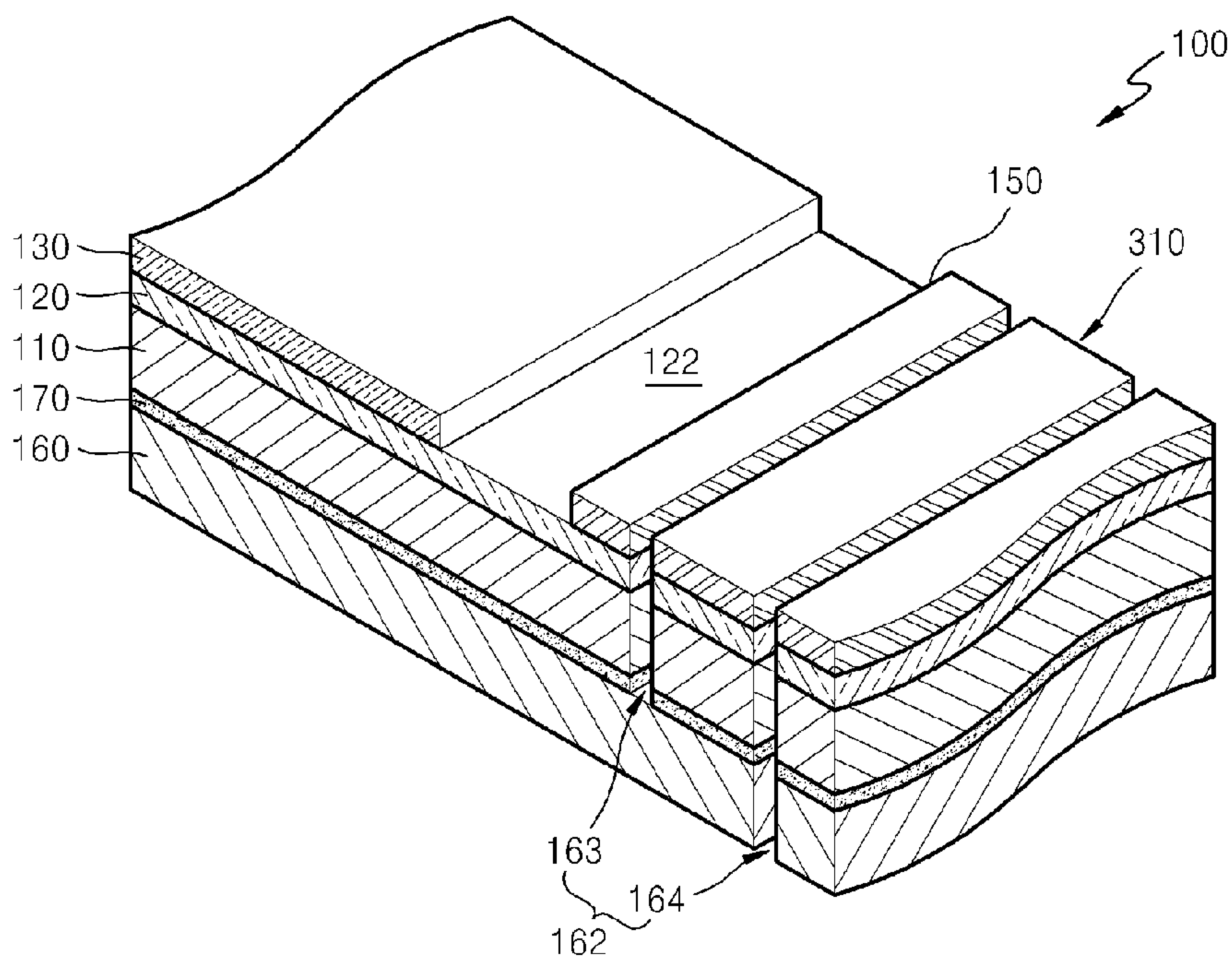
110
170
160
122
163
164
162

FIG. 3B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164
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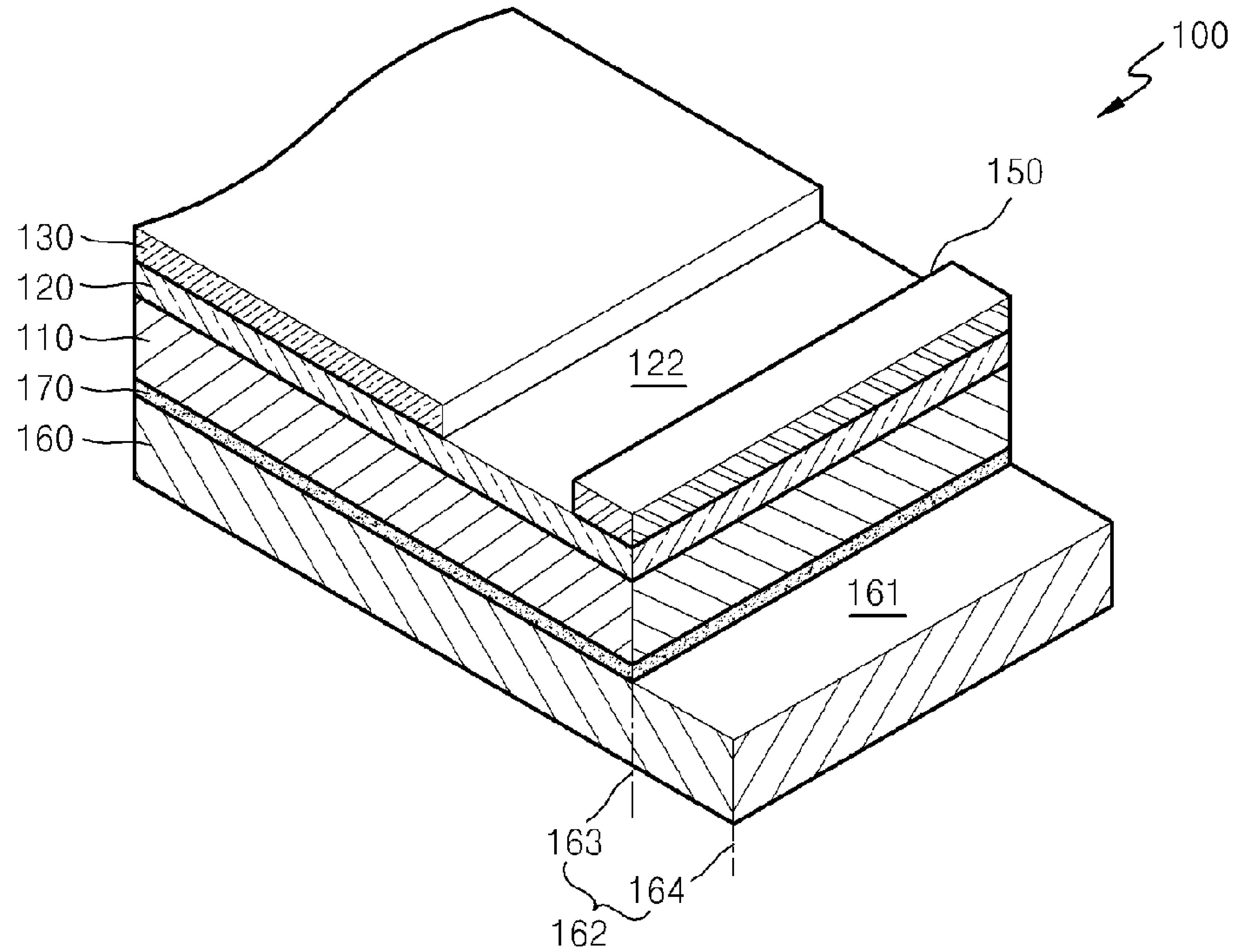
FIG. 3C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163
164
162

FIG. 3D

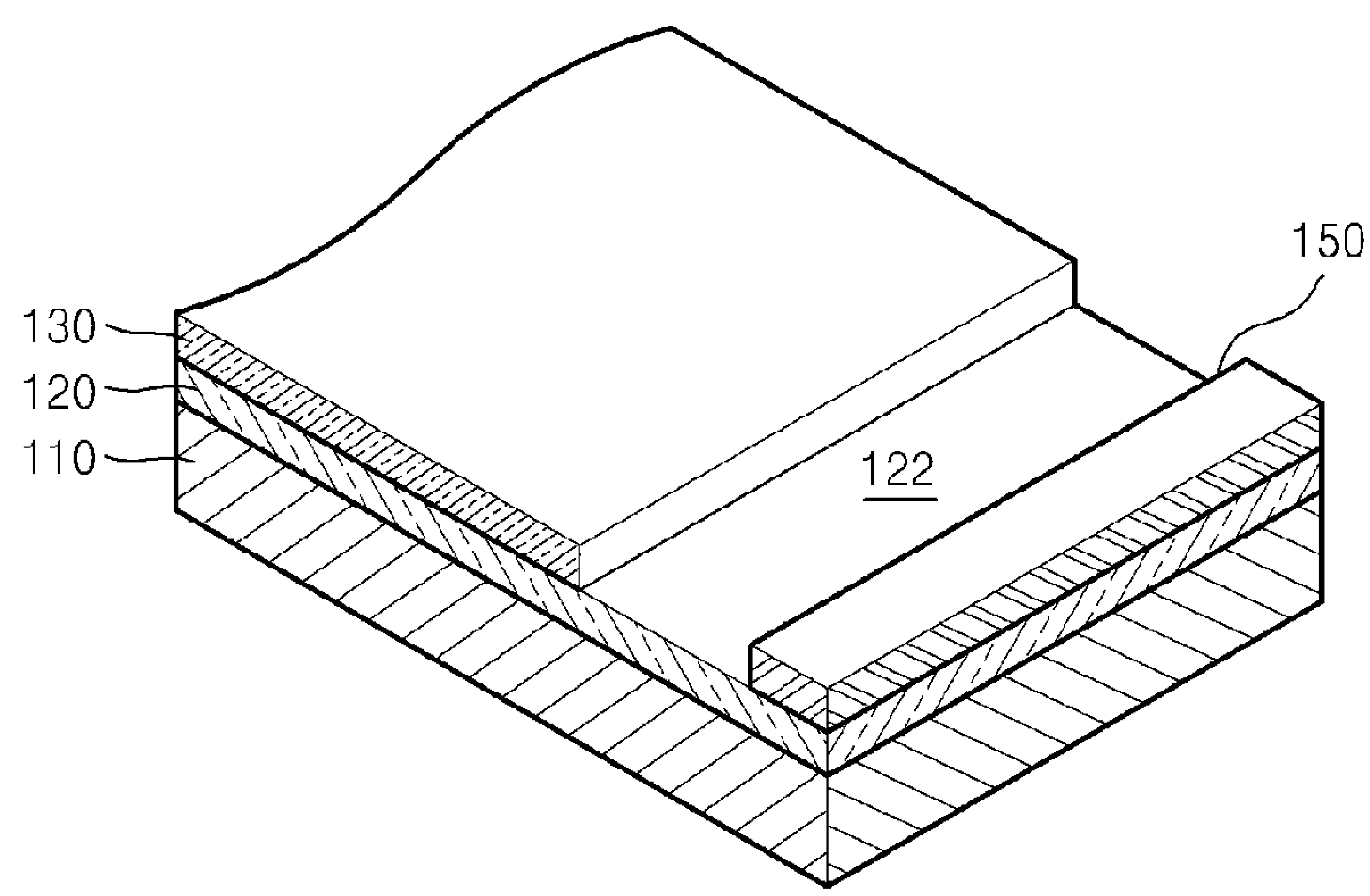
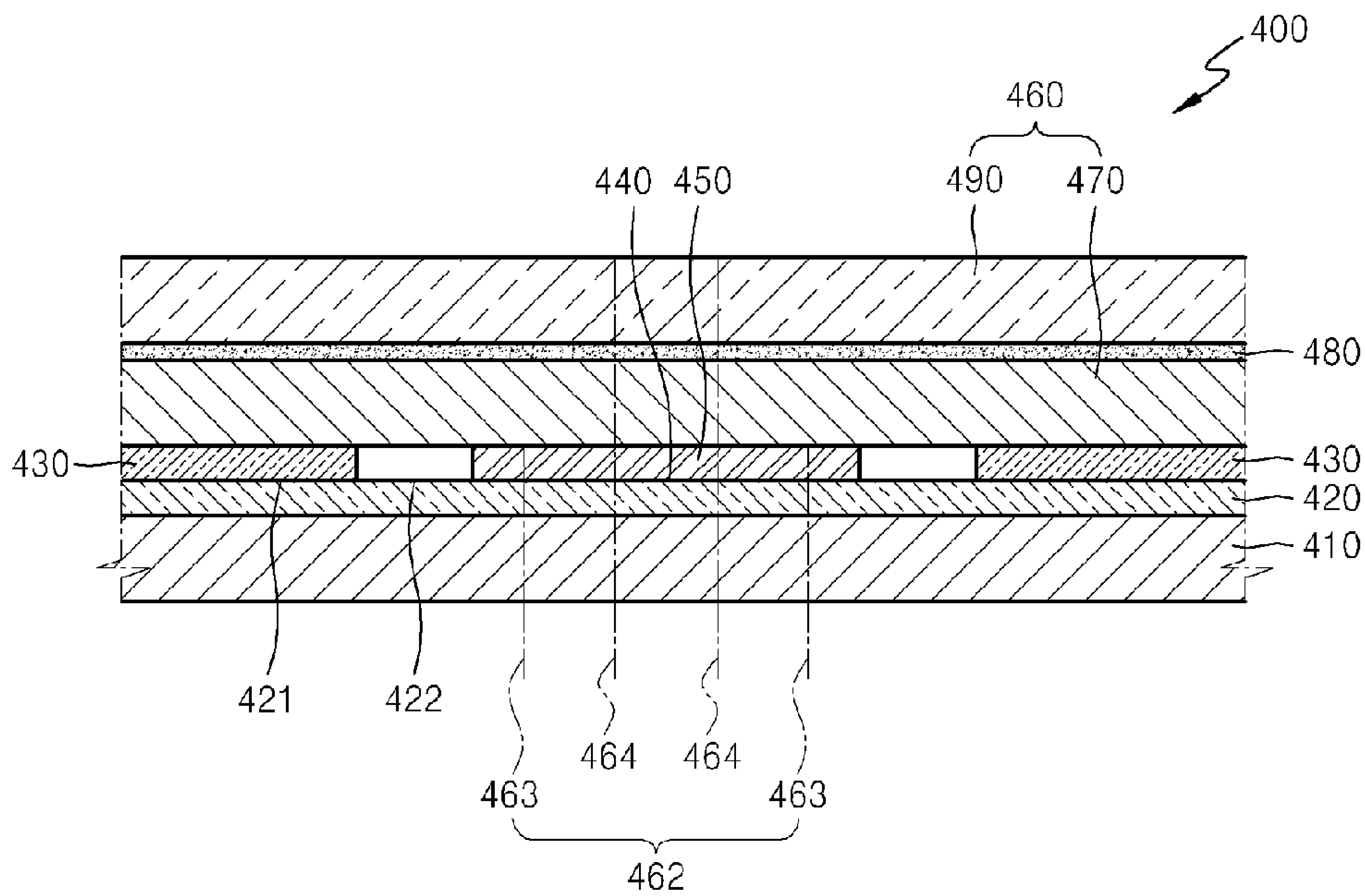

150
130
120
110
122

FIG. 4A


400
460
440 450
490 470
480
430
430
420
410
421
422
464
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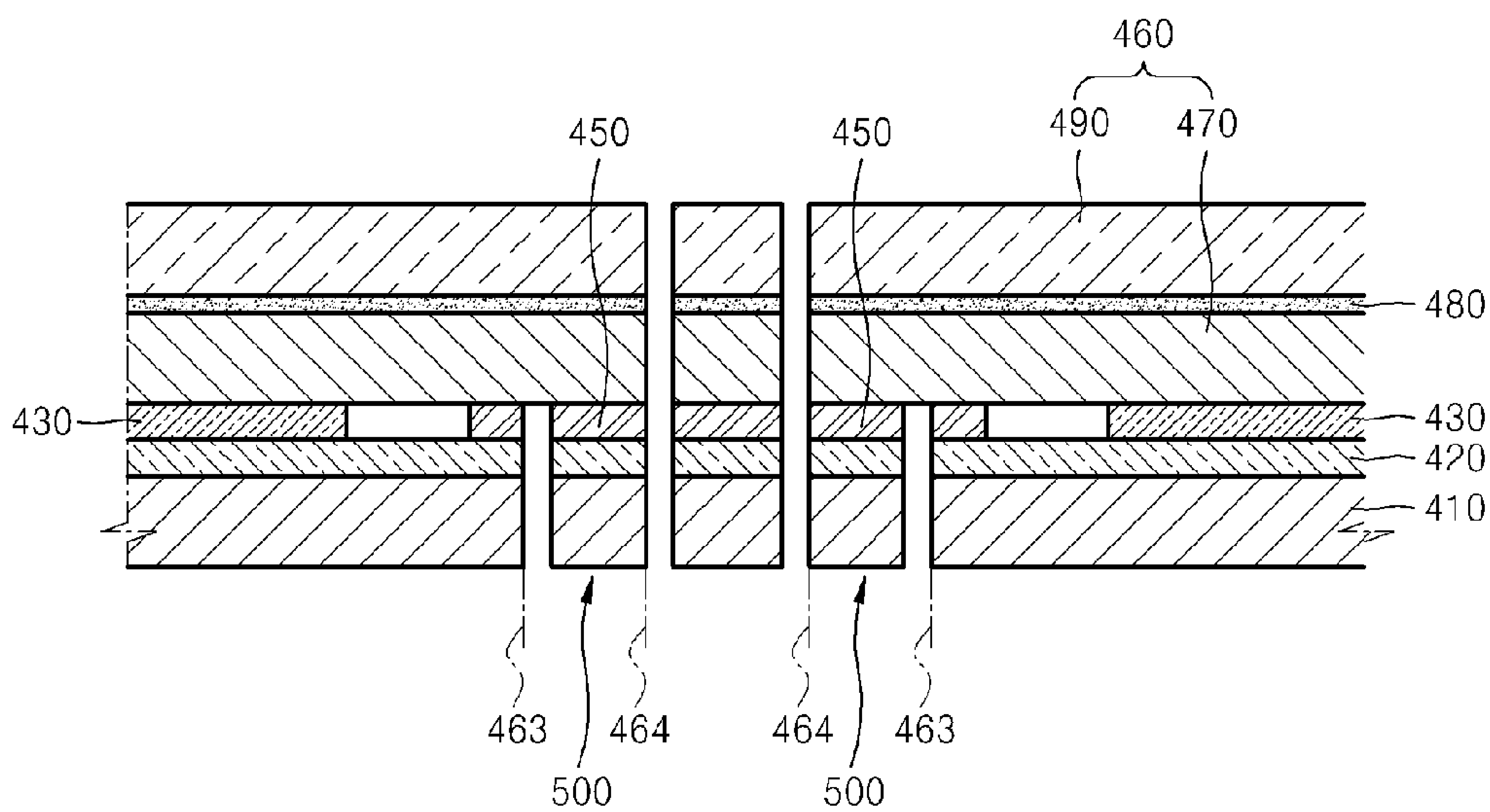
463
463
462

FIG. 4B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464
463
500
500

FIG. 4C

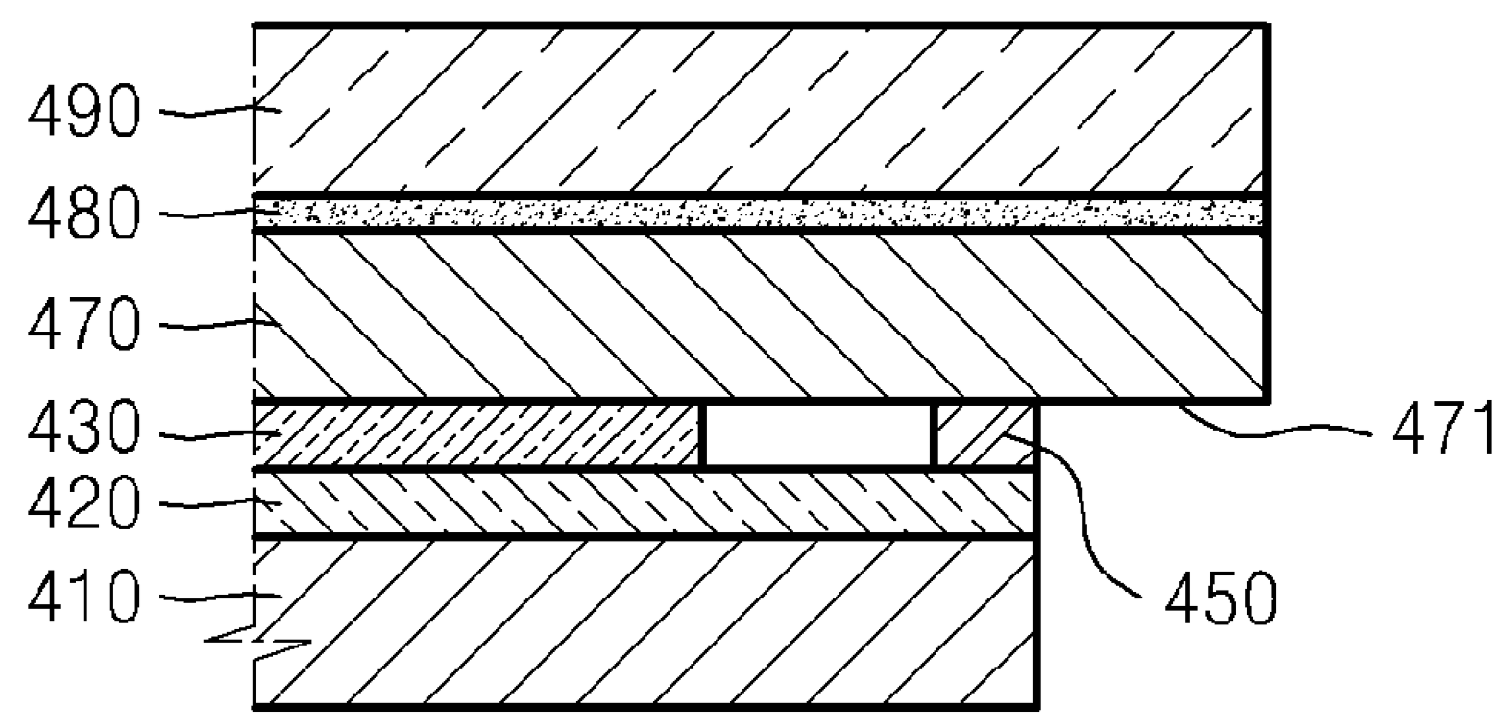
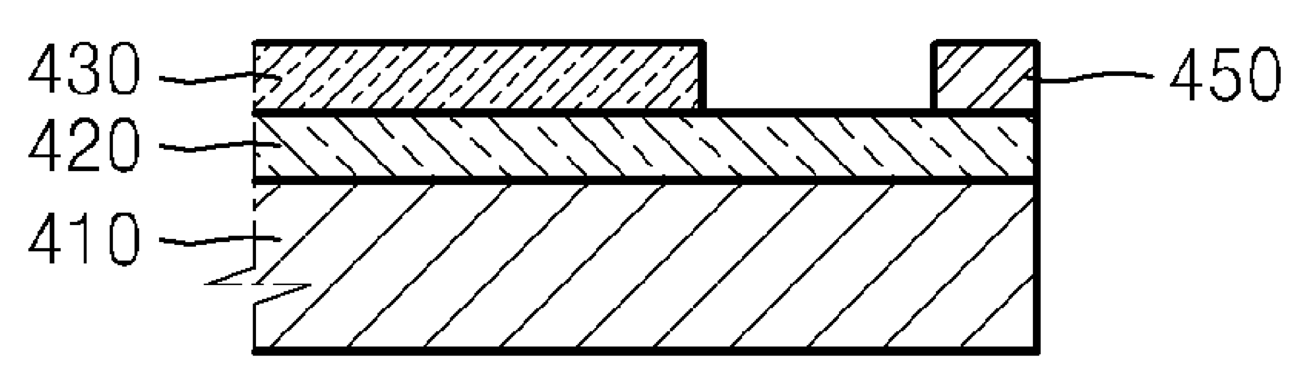


FIG. 4D



ARRAY SUBSTRATE FOR FLEXIBLE DISPLAY DEVICE AND METHOD OF MANUFACTURING THE ARRAY SUBSTRATE

CROSS-REFERENCE TO RELATED APPLICATION

This application claims priority to and the benefit of Korean Patent Application No. 10-2012-0112082, filed in the Korean Intellectual Property Office on Oct. 9, 2012, the disclosure of which is incorporated herein by reference in its entirety.

BACKGROUND

1. Field

The described technology generally relates to an array substrate, and more particularly, to an array substrate for a flexible display device in which an edge crack of a flexible display unit is prevented, and a method of manufacturing the array substrate.

2. Description of the Related Technology

In general, flat display devices are typically classified into a light-emitting type display device and a light-receiving type display device. Examples of the light-emitting type display device include an organic light-emitting display device, a plasma display panel (PDP), a flat cathode ray tube (FCRT), a vacuum fluorescent display panel (VFD), a light emitting diode (LED) panel, or the like. An example of the light-receiving type display device includes a liquid crystal display (LCD) panel.

Among the flat display devices, organic light-emitting display devices are advantageous in that they have wide viewing angles, an excellent contrast ratio, and high response speeds. Accordingly, the organic light-emitting display devices are highlighted for application to display devices for mobile devices such as a digital camera, a video camera, a camcorder, a portable information terminal, a smart phone, an ultra-slim notebook, a table personal computer, or the like or electronic/electric appliances, such as ultra-thin TVs.

Recently, flexible display devices have been studied and developed as next-generation display devices for certain applications in that they are easilied carried and may be applied devices having various shapes.

For efficiency, a flexible display device may be manufactured by forming a plurality of display devices on a mother substrate and cutting the plurality of display devices into individual display devices with a cutting tool. The flexible display device may include a flexible substrate having a hardness that is lower than a hardness of a glass substrate having rigidity.

Thus, in the manufacturing method including a cutting process, cracks may occur in the flexible display device due to equipment stress or due to an external force by a worker. In general, the cracks occur in the manufacturing method when the flexible display device contacts a surface of a stage while the flexible display device is mounted on the stage, or when a worker handles the flexible display device for a test.

When the cracks occur in the flexible display device, a film of a thin-film encapsulation (TFE) unit that covers a display unit may be damaged, and thus, foreign moisture may penetrate into the flexible display device. Thus, the flexible display device has a defect that may cause a problem with non-lighting or the like.

SUMMARY

The present embodiments provide an array substrate for a flexible display device in which incidence of an edge crack,

that occurs when a plurality of flexible display units on a mother substrate are individually divided, is decreased. Some embodiments provide a method of manufacturing the array substrate.

Some embodiments provide a method of manufacturing an array substrate for a flexible display device, the method including operations of arranging at least one lower protective film, wherein a plurality of display units that are covered by thin-film encapsulation (TFE) units are arrayed on the at least one lower protective film; performing half cutting and full cutting on the at least one lower protective film to provide remaining parts on the at least one lower protective film; and removing the remaining parts on the at least one lower protective film from the half cutting and full cutting.

In some embodiments, the operation of arranging the at least one lower protective film may include an operation of arranging a first lower protective film on which the plurality of display units are arrayed and a second lower protective film that is attached to the first lower protective film by using an adhesion layer.

In some embodiments, the method may further include operations of arraying the plurality of display units at regular intervals on the first lower protective film, wherein each of the plurality of display units includes a display region and a non-display region; and forming a plurality of testing wires in a wire region between adjacent display units of the plurality of display units, wherein the plurality of testing wires are electrically connected to the adjacent display units, respectively.

In some embodiments, the operation of performing the half cutting and full cutting may include operations of performing the half cutting along a half cutting line whereby the plurality of display units are individually divided along edges of the plurality of display units; and performing the full cutting along a full cutting line in the wire region between the adjacent display units.

In some embodiments, the half cutting may be performed from a top surface of each of the plurality of display units to a bottom surface of the first lower protective film in a half-cut region, and the full cutting may be performed from a top of the plurality of testing wires to a bottom surface of the second lower protective film in a full-cut region.

In some embodiments, the full cutting line may overlap with the plurality of testing wires, and the half cutting line may cross a portion of the plurality of testing wires.

In some embodiments, the operation of arranging the at least one lower protective film may further include an operation of arranging a first upper protective film that is arranged on a top surface of the plurality of display units which is in an opposite direction to the at least one lower protective film, and a second upper protective film that is attached to the first upper protective film by using an adhesion layer.

In some embodiments, the method may further include operations of arraying the plurality of display units at regular intervals on the at least one lower protective film, wherein each of the plurality of display units includes a display region and a non-display region; forming a plurality of testing wires in a wire region between adjacent display units of the plurality of display units, wherein the plurality of testing wires are electrically connected to the adjacent display units, respectively; attaching the first upper protective film to the top surface of the plurality of display units covered by the TFE units; and attaching the second upper protective film to a top surface of the first upper protective film.

In some embodiments, the operation of performing the half cutting and full cutting may include operations of performing the half cutting along a half cutting line whereby the plurality of display units are individually divided along edges of the plurality of display units; and performing the full cutting along a full cutting line in the wire region between the adjacent display units.

In some embodiments, the half cutting may be performed from a top surface of the at least one lower protective film to the top surface of the first upper protective film, and the full cutting may be performed from the top surface of the at least one lower protective film to a bottom surface of the second upper protective film.

In some embodiments, the full cutting line may overlap with the plurality of testing wires, and the half cutting line may cross a portion of the plurality of testing wires.

Some embodiments provide an array substrate for a flexible display device, the array substrate including at least one lower protective film; a plurality of display units arrayed at regular intervals on the at least one lower protective film, wherein each of the plurality of display units includes a display region for displaying an image and a non-display region extending from the display region to an edge of each of the plurality of display units; a thin-film encapsulation (TFE) unit covering the display region of each of the plurality of display units; and a plurality of testing wires formed in a wire region between adjacent display units of the plurality of display units, wherein the plurality of testing wires are electrically connected to the adjacent display units, respectively, wherein the at least one lower protective film includes a first lower protective film on which the plurality of display units are arrayed, and a second lower protective film that is attached to the first lower protective film by using an adhesion layer and that is configured to be selectively removed.

In some embodiments, each of the plurality of display units may include a flexible substrate formed on the at least one lower protective film; a thin-film transistor (TFT) formed on the flexible substrate, the TFT including a semiconductor active layer, a gate electrode, source and drain electrodes, and a plurality of insulating layers for insulating the semiconductor active layer, the gate electrode, the source and drain electrodes from each other; and an organic light-emitting device (OLED) connected to the TFT, the OLED including a first electrode, a second electrode, and an organic layer formed between the first electrode and the second electrode.

In some embodiments, the array substrate may further include a buffer layer; a gate insulating layer; and an interlayer insulating layer, wherein the plurality of insulating layers may include a first insulating layer that is formed on the flexible substrate, wherein the first insulating layer corresponds to the buffer layer; a second insulating layer that covers the semiconductor active layer formed on the first insulating layer, wherein the first insulating layer corresponds to the gate insulating layer; and a third insulating layer that covers the gate electrode formed on the second insulating layer, wherein the third insulating layer corresponds to the interlayer insulating layer, wherein at least one of the first insulating layer, the second insulating layer, and the third insulating layer extends from the display region of each of the plurality of display units to the wire region.

Some embodiments provide an array substrate for a flexible display device, the array substrate including a lower protective film; a plurality of display units arrayed at regular intervals on the lower protective film, wherein each of the plurality of display units includes a display region for displaying an image and a non-display region extending from the display region to an edge of each of the plurality of display units; a thin-film encapsulation (TFE) unit covering the display region of each of the plurality of display units; and an upper protective film formed on the plurality of display units, wherein the upper protective film comprises a first upper protective film that is formed on the plurality of display units covered by a plurality of the TFE units, and a second upper protective film that is attached to the first upper protective film by using an adhesion layer.

BRIEF DESCRIPTION

The above and other features and advantages of the present embodiments will become more apparent by describing in detail exemplary embodiments thereof with reference to the attached drawings in which:

FIG. **1** illustrates an array substrate for a flexible display device according to an aspect of the present embodiments;

FIG. **2** is a cross-sectional view illustrating a sub-pixel of a display unit of FIG. **1**;

FIGS. **3**A through **3**D illustrate a process of forming individual display units, according to an aspect of the present embodiments,

FIG. **3**A is a cross-sectional perspective view illustrating a state in which a display unit is formed on a mother substrate,

FIG. **3**B is a cross-sectional perspective view illustrating a state in which half cutting and full cutting are performed on the mother substrate of FIG. **3**A,

FIG. **3**C is a cross-sectional perspective view illustrating a state in which a remaining part on the mother substrate of FIG. **3**B is removed, and

FIG. **3**D is a cross-sectional perspective view illustrating a state in which a second lower protective film arranged on the mother substrate of FIG. **3**C is removed; and

FIGS. **4**A through **4**D illustrate a process of forming individual display units, according to another embodiment of the present invention,

FIG. **4**A is a cross-sectional perspective view illustrating a state in which an upper protective film is formed on a mother substrate,

FIG. **4**B is a cross-sectional perspective view illustrating a state in which half cutting and full cutting are performed on the mother substrate of FIG. **4**A,

FIG. **4**C is a cross-sectional perspective view illustrating a state in which a remaining part on the mother substrate of FIG. **4**B is removed, and

FIG. **4**D is a cross-sectional perspective view illustrating a state in which the upper protective film arranged on the mother substrate of FIG. **4**C is removed.

DETAILED DESCRIPTION

The present embodiments will now be described more fully with reference to the accompanying drawings, in which exemplary embodiments are shown. The invention may be embodied in many different forms, and should not be construed as being limited to the embodiments set forth herein. Thus, the invention may include all revisions, equivalents, or substitutions which are included in the concept and the technical scope related to the present embodiments.

While such terms as "first", "second", etc., may be used to describe various components, such components must not be limited to the above terms. The above terms are used only to distinguish one component from another.

The terms used in the present specification are merely used to describe particular embodiments, and are not intended to limit the present embodiments. An expression used in the singular encompasses the expression of the plural, unless it has a clearly different meaning in the context. In the present specification, it is to be understood that the terms such as "including" or "having," etc., are intended to indicate the existence of the features, numbers, steps, actions, components, parts, or combinations thereof disclosed in the specification, and are not intended to preclude the possibility that one or more other features, numbers, steps, actions, components, parts, or combinations thereof may exist or may be added.

Hereinafter, exemplary embodiments of the present embodiments will be described in detail with reference to the attached drawings Like reference numerals in the drawings denote like elements and detailed descriptions thereof are omitted here.

As used herein, the term "and/or" includes any and all combinations of one or more of the associated listed items.

Expressions such as "at least one of," when preceding a list of elements, modify the entire list of elements and do not modify the individual elements of the list.

FIG. **1** illustrates an array substrate **100** for a flexible display device according to an aspect of the present embodiments.

Referring to FIG. **1**, the array substrate **100** includes a mother substrate **110**, a plurality of display units **120** formed on the mother substrate **110**, thin-film encapsulation (TFE) units **130** formed respectively on the display units **120**, and a plurality of testing wires **150** patterned on the mother substrate **110**.

In some embodiments, the mother substrate **110** may be a flexible film, such as a protective film, formed of a polymer resin. In some embodiments, the mother substrate **110** may have a sufficient thickness to support a shape of the display units **120** that are thin-film layers. In some embodiments, the mother substrate **110** may have a size by which the display units **120** may be simultaneously manufactured.

In some embodiments, the display units **120** may be arrayed at regular intervals on the mother substrate **110**. In some embodiments, the display units **120** may be individually separated to function as display devices, respectively. In some embodiments, the display units **120** that are simultaneously formed on the mother substrate **110** may be individually separated by using a cutting tool.

In some embodiments, each of the display units **120** corresponds to an organic light-emitting display unit, but the display unit **120** may also be applied to different types of display units, such as a liquid crystal display (LCD) unit, a field emission display device, an electroluminescent display unit, an electrophoretic display unit, or the like.

In some embodiments, the display unit **120** may be divided into a display region **121** that realizes an image, and a non-display region **122** that extends from the display region **121** to an edge of the display unit **120**. Devices or thin-film layers formed in the display region **121** will be described in detail with reference to FIG. **2**.

The TFE unit **130** that covers the display region **121** is formed on the display unit **120**. The TFE unit **130** prevents exterior moisture or foreign substances from penetrating into the display region **121**. In some embodiments, the TFE unit **130** may be formed on an entire surface of the mother substrate **110**. In some embodiments, it is preferable that the TFE unit **130** is selectively formed on corresponding regions of the display units **120**, respectively. In some embodiments, the TFE unit **130** may be formed via a deposition process using a deposition mask.

The testing wires **150** are patterned in a wire region **140** between the display units **120** that are adjacent to each other. In some embodiments, the testing wires **150** are electrically connected to the display units **120** to test whether the display units **120** are normally turned on.

The testing wires **150** are disposed in one direction (e.g., a Y-axis direction) of the mother substrate **110**. In some embodiments, the testing wires **150** may be disposed in the Y-axis direction of the mother substrate **110**. However, aspects of the present embodiments are not limited thereto and the testing wires **150** may extend in an X-axis direction of the mother substrate **110** or may simultaneously extend in the X-axis and Y-axis directions of the mother substrate **110**, i.e., a structure of the testing wires **150** is not limited to the aforementioned as long as the testing wires **150** are electrically connected to the plurality of display units **120**, respectively.

In some embodiments, each of the testing wires **150** may be drawn as one whole wire but may be formed as a plurality of wires along one direction of the mother substrate **110**.

FIG. **2** is a cross-sectional view illustrating a sub-pixel of the display unit **120** of FIG. **1**.

Referring to FIG. **2**, the display unit **120** includes a flexible substrate **171**. In some embodiments, the flexible substrate **171** may be formed of a flexible material. For example, the flexible substrate **171** may be formed of a polymer material including polyimide (PI), polycarbonate (PC), polyethersulfone (PES), polyethylene terephthalate (PET), polyethylene naphthalate (PEN), polyarylate (PAR), fiber glass reinforced plastic (FRP), and the like.

In some embodiments, the flexible substrate **171** is a thin-film layer that completely covers the mother substrate **110** of FIG. **1**. In some embodiments, if the flexible substrate **171** has a sufficient thickness to support weights of devices and thin-film layers which are formed thereon, the flexible substrate **171** may replace the mother substrate **110**.

A first insulating layer **172** that corresponds to a barrier layer is formed on the flexible substrate **171**. In some embodiments, the first insulating layer **172** completely covers the flexible substrate **171**. In some embodiments, the first insulating layer **172** may include an inorganic material, such as silicon oxide (SiO_x), silicon nitride (SiN_y), silicon oxynitride (SiON), aluminum oxide (AlO), aluminum nitride (AlON), or the like, may include an organic material, such as acryl, polyimide, polyester, or the like, or may be formed as a multi-layer stack including the organic material and the inorganic material.

In some embodiments, the first insulating layer **172** shields from oxygen and moisture, prevents moisture or foreign substances from diffusing from the flexible substrate **171**, and provides a flat surface on the flexible substrate **171**.

A thin-film transistor (TFT) is formed on the first insulating layer **172**. In some embodiments, the TFT may be a top gate type TFT. In some embodiments, the TFT may be different types of TFTs, such as a bottom gate type TFT.

In some embodiments, a semiconductor active layer **175**, a second insulating layer **173**, a gate electrode **179**, a third insulating layer **174**, a source electrode **180**, a drain electrode **181**, and a protective layer **183** are formed on the first insulating layer **172** when TFT is a top gate type TFT.

When the semiconductor active layer **175** is formed of polysilicon, the semiconductor active layer **175** may be formed in a manner that amorphous silicon is first formed and then is crystallized into polysilicon.

In some embodiments, the crystallization of the amorphous silicon may be performed by using various methods including a rapid thermal annealing (RTA) method, a solid phase crystallization (SPC) method, an excimer laser annealing (ELA) method, a metal-induced crystallization (MIC) method, a metal-induced lateral crystallization (MILC) method, a sequential lateral solidification (SLS) method, and the like. In some embodiments, in order to apply the flexible substrate **171**, it is preferable not to use a crystallization method that does not require a high-temperature heating process to be performed.

In some embodiments, when the crystallization is performed via a low temperature polysilicon (LTPS) process, the semiconductor active layer **175** may be activated by being irradiated a laser for a short time, so that the flexible substrate **171** is not exposed to a high temperature equal to or greater than 300° C., and thus a whole process may be performed at a temperature equal to or less than 300° C. Accordingly, the TFT may be formed by using the flexible substrate **171** that is formed of a polymer material.

In some embodiments, the semiconductor active layer **175** is formed with a source region **176** and a drain region **177** which may be doped with p-type impurity ions. In some embodiments, a channel region **178** that is not doped with an impurity corresponds to a region between the source region **176** and the drain region **177**.

The second insulating layer **173** that corresponds to a gate insulating layer is formed on the semiconductor active layer **175**. In some embodiments, the second insulating layer **173** may be a single layer including SiO_2 or may have a double-layer structure including SiO_2 and SiN_y. In some embodiments, the second insulating layer **173** may correspond to an entire region of the display unit **120**. In some embodiments, the second insulating layer **173** may extend to and thus is formed in the non-display region **122** of FIG. **1**. In some embodiments, the second insulating layer **173** may extend to the wire regions **140** of FIG. **1** and thus may be formed on a mother substrate (refer to the mother substrate **110** of FIG. **1**). In some embodiments, the second insulating layer **173** may be selectively formed on desired regions of the mother substrate **110**.

In some embodiments, the gate electrode **179** may be formed on a predetermined region of the second insulating layer **173**. The gate electrode **179** is connected to a gate line (not shown) to apply TFT on/off signals to the TFT. In some embodiments, the gate electrode **179** may be formed of a single metal material or metal materials. For example, the gate electrode **179** may include a single layer structure or a multi-layer structure including Au, Ag, Cu, Ni, Pt, Pd, Al, Mo, Cr, or the like, or may include a metal alloy, such as an Al:Nd alloy, a Mo:W alloy, and the like. The third insulating layer **174** that corresponds to an interlayer insulating layer is formed on the gate electrode **179**. In some embodiments, the third insulating layer **174** may be formed of an insulating material, such as SiO_2 or SiN_y, or an insulating organic material. In some embodiments, the third insulating layer **174** may correspond to an entire region of the display unit **120**. That is, the third insulating layer **174** extends to and thus is formed in the non-display region **122** of FIG. **1**. In some embodiments, the third insulating layer **174** may also extend to the wire regions **140** of FIG. **1** and thus may be formed on the mother substrate **110** of FIG. **1**. In some embodiments, the third insulating layer **174** may be selectively formed on desired regions of the mother substrate **110**.

In some embodiments, in the non-display region **122** and the wire regions **140**, the flexible substrate **171** is formed on the mother substrate **110**, and at least one of the first insulating layer **172**, the second insulating layer **173**, and the third insulating layer **174** may be stacked on the flexible substrate **171**.

The source electrode **180** and the drain electrode **181** are formed on the third insulating layer **174**. In some embodiments, by selectively removing portions of the second insulating layer **173** and the third insulating layer **174**, contact holes **182** may be formed in the second insulating layer **173** and the third insulating layer **174**, so that the source electrode **180** is electrically connected to the source region **176** via the contact hole **182**, and the drain electrode **181** is electrically connected to the drain region **177** via the contact hole **182**.

The protective layer **183** is formed on the source electrode **180** and the drain electrode **181**. In some embodiments, the protective layer may be a passivation layer and/or a planarization layer. In some embodiments, the protective layer **183** protects and planarizes the TFT formed therebelow. The protective layer **183** may be formed in various manners. In some embodiments, the protective layer **183** may be formed of an organic material, such as benzocyclobutene (BCB), acryl, or the like, or an inorganic material, such as SiN_y or the like, and may have one of various structures including a single-layer structure, a double-layer structure, or a multi-layer structure.

A display device is formed on the TFT. In some embodiments, the display device may be formed as an organic light-emitting device (OLED). However, aspects of the present invention are not limited thereto, and various display devices may be used.

In order to form the OLED on the TFT, a first electrode **185** that corresponds to a pixel electrode is electrically connected to one of the source electrode **180** and the drain electrode **181** via a contact hole **184**.

In some embodiments, the first electrode **185** may function as an anode electrode between electrodes that are arranged in the OLED and may be formed of various conductive materials. In some embodiments, the first electrode **185** may be formed as a transparent electrode or a reflective electrode according to purpose.

For example, when the first electrode **185** is used as a transparent electrode, the first electrode **185** may include ITO, IZO, ZnO, In_2O_3 or the like, and when the first electrode **185** is used as a reflective electrode, the first electrode **185** may be formed in a manner that a reflective layer is formed of Ag, Mg, Al, Pt, Pd, Au, Ni, Nd, Ir, Cr, or compound of any of these, and then ITO, IZO, ZnO, In_2O_3, or the like is formed thereon.

In some embodiments, a pixel-defining layer (PDL) **186** that is formed of an organic material and covers edges of the first electrode **185** of the OLED is formed on the protective layer **183**. In some embodiments, an organic layer **187** is formed on an exposed portion of the first electrode **185**, which is formed by etching a portion of the PDL **186**.

In some embodiments, the organic layer **187** is patterned to only correspond to each sub-pixel, i.e., the patterned first electrode **185**. However, this structure is for convenience of description and thus the organic layer **187** may be integrally formed with another organic layer **187** of another adjacent sub-pixel. In some embodiments, some layers of the organic layer **187** may be formed to correspond to sub-pixels, respectively, and other layers of the organic layer **187** may be integrally formed with another organic layer **187** of another adjacent sub-pixel.

In some embodiments, the organic layer **187** may be formed as a low molecule organic material layer or a polymer organic material layer.

When the organic layer **187** is formed as a low molecule organic material layer, the organic layer **187** may have a structure in which a hole injection layer (HIL), a hole transport layer (HTL), an emission layer (EML), an electron transport layer (ETL), an electron injection layer (EIL), or the like are singularly or multiply stacked.

In some embodiments, the organic layer **187** may be formed by using one of various organic materials including copper phthalocyanine (CuPc), N,N'-Di(naphthalene-1-yl)-N,N'-diphenyl-benzidine (NPB), tris-8-hydroxyquinoline aluminum)(Alq3), or the like.

When the organic layer **187** is formed as a polymer organic material layer, the organic layer **187** may have a structure including an HTL and an EML. The HTL is formed of PEDOT, and the EML is formed of a polymer organic material including a poly-phenylenevinylene (PPV) material, a polyfluorene material, and the like. The polymer organic material layer may be formed by using a screen printing method, an inkjet printing method, or the like.

However, features of the organic layer **187** are not limited thereto and thus various examples may be applied thereto.

A second electrode **188** that corresponds to a common electrode of the OLED is formed on the organic layer **187**.

The first electrode **185** and the second electrode **188** are insulated from each other by the organic layer **187**. When a voltage is applied to the first electrode **185** and the second electrode **188**, visible rays are emitted from the organic layer **187** so that an image that is recognizable by a user is realized.

Likewise to the first electrode **185**, the second electrode **188** may be formed as a transparent electrode or a reflective electrode.

When the second electrode **188** is formed as a transparent electrode, the second electrode **188** may be formed in a manner that a metal material with a low work function, e.g., Li, Ca, LiF/Ca, LiF/Al, Al, Mg, or compound of any of these, is deposited on the organic layer **187**, and then a transparent electrode target material including ITO, IZO, ZnO, In_2O_3, or the like is formed thereon.

When the second electrode **188** is formed as a reflective electrode, the second electrode **188** may be formed in a manner that Li, Ca, LiF/Ca, LiF/Al, Al, Mg, or compound of any of these is completely deposited.

When the first electrode **185** is formed as a transparent electrode or a reflective electrode, the first electrode **185** may have a shape that corresponds to a shape of an opening of each sub-pixel. In some embodiments, the second electrode **188** may be formed by depositing a transparent electrode or a reflective electrode on an entire surface of the display region **121**. In some embodiments, the second electrode **188** may not be deposited on the entire surface and thus may be formed as various patterns. Here, positions of the first electrode **185** and the second electrode **188** may be switched.

The TFE unit **130** is combined on the OLED. In some embodiments, the TFE unit **130** may protect the organic layer **187** and other thin-film layers against exterior moisture or oxygen. In some embodiments, the TFE unit **130** may encapsulate the OLED in a manner that organic and/or inorganic films are formed on the OLED after the OLED is manufactured. In some embodiments, the TFE unit **130** may be formed of the same material as the flexible substrate **171**.

In some embodiments, a buffer layer (not shown) may be further formed on one surface of the encapsulation unit **130** which faces the OLED. In some embodiments, the buffer layer may be formed of an inorganic material, such as SiO_x, SiN_y, SiON, AlO, or AlON, may be formed of an organic material, such as acryl, polyimide, or the like, or may be formed as a multi-layer stack including the organic material and the inorganic material.

Referring back to FIG. **1**, the display units **120** that are arrayed at regular intervals on the mother substrate **110** undergo a cutting process so as to be divided into individual display devices.

For the division, first cutting lines **161** and second cutting lines **162** are formed on the mother substrate **110** so that the display units **120** are individually separated along edges of the display units **120**. In some embodiments, the first cutting lines **161** and second cutting lines **162** include a plurality of first cutting lines that are formed along opposite edges of the display units **120** in an X-axis direction of the array substrate **100**, and a plurality of second cutting lines that are formed along opposite edges of the display units **120** in a Y-axis direction of the array substrate **100**.

By using a cutting tool, the array substrate **100** having the aforementioned structure is cut along the first cutting lines **161** so that a group of the display units **120** sequentially arrayed in the X-axis direction is separated, and then the group of display units **120** are cut along the second cutting lines **162** so that the display units **120** are individually separated.

Here, at least one testing wire **150** is formed in the wire region **140** between the adjacent display units **120**. There is a limit in decreasing a width of the testing wire **150** due to its electrical characteristic, and also, since the wire region **140** is narrow, a cutting operation is performed while the testing wire **150** overlaps with the first cutting line **161** or the second cutting line **162** on the mother substrate **110**.

Here, while or after the display units **120** are divided into individual display devices, an edge crack occurs in the first cutting line **161** or the second cutting line **162** which is formed at an edge of the display unit **120**.

After the edge crack occurs, if equipment or a work contacts the array substrate **100** for a flexible display device, the edge crack at a contacted part of the edge of the display unit **120** further rapidly propagates.

In order to prevent the aforementioned problem, in some embodiments, the mother substrate **110** may be formed of a plurality of protective films, and is divided into individual display units by using half cutting and full cutting.

This will now be described below.

FIGS. **3**A through **3**D illustrate a process of forming individual display units, according to an aspect of the present embodiments. FIG. **3**A is a cross-sectional perspective view illustrating a state in which a display unit is formed on a mother substrate, FIG. **3**B is a cross-sectional perspective view illustrating a state in which half cutting and full cutting are performed on the mother substrate of FIG. **3**A, FIG. **3**C is a cross-sectional perspective view illustrating a state in which a remaining part on the mother substrate of FIG. **3**B is removed, and FIG. **3**D is a cross-sectional perspective view illustrating a state in which a second lower protective film arranged on the mother substrate of FIG. **3**C is removed.

Here, the array substrate **100** for a flexible display device has been cut along the first cutting line **161** in the X-axis direction of FIG. **1**.

First, as illustrated in FIG. **3**A, the array substrate **100** for a flexible display device is arranged.

The array substrate **100** includes a plurality of lower protective films. The lower protective films include a first lower protective film **110** and a second lower protective film **160**. In some embodiments, the first lower protective film **110** and the second lower protective film **160** are formed of a flexible material, such as polymer resin.

In some embodiments, the first lower protective film **110** functions as a mother substrate having a size by which the display units **120** may be simultaneously manufactured.

In some embodiments, the display units **120** are arrayed in one direction on a top surface of the first lower protective film **110**. Each of the display units **120** includes the display region **121** and the non-display region **122** that extends from the display region **121** to an edge of the display unit **120**. The display region **121** is covered by the TFE unit **130**.

A wire region (refer to the wire region **140** of FIG. **1**) is formed between a pair of adjacent display units **120**. The testing wire **150** having a stripe shape is patterned in the wire region **140**. At least one testing wire **150** is formed in one direction of the array substrate **100**.

The second lower protective film **160** is attached to a bottom surface of the first lower protective film **110**. In some embodiments, the second lower protective film **160** may be attached to the bottom surface of the first lower protective film **110** by using an adhesion layer **170**. In some embodiments, the adhesion layer **170** may be formed of a material having low adhesion so as to facilitate easy detachment of the display units **120**.

In some embodiments, the adhesion layer **170** may be separately arranged, and then may be interposed between the first lower protective film **110** and the second lower protective film **160** or may be coated in a liquid state on at least one of the bottom surface of the first lower protective film **110** and a top surface of the second lower protective film **160** of FIG. **3**A. In some embodiments, the adhesion layer **170** may be coated on the top surface of the second lower protective film **160**.

In order to individually divide the display units **120**, the second cutting line **162** is formed on the first lower protective film **110** along the Y-axis direction of FIG. **1**. The second cutting line **162** includes a half cutting line **163** that is formed along an edge of the display unit **120** so as to separate the display unit **120**, and a full cutting line **164** that is arranged in the wire region **140** between the pair of adjacent display units **120**. The half cutting line **163** corresponds to the edge of the display unit **120**.

Although not illustrated, in some embodiments of the manufacturing method, at least one upper protective film may be further attached to a top surface of the display unit **120** so as to protect the TFE unit **130**, the display unit **120**, and the testing wire **150**.

Referring to FIG. **3**B, by performing half cutting and full cutting on the first lower protective film **110**, the display units **120** are individually divided.

In some embodiments, the half cutting is performed along the half cutting line **163** that is formed along the edge of the display unit **120**. In some embodiments, the half cutting is performed in a manner that a cutting tool cuts the array substrate **100** in a thickness direction from the top surface of the display unit **120** to the bottom surface of the first lower protective film **110**. In some embodiments, the second lower protective film **160** is not cut.

In some embodiments, since the half cutting line **163** is formed in a region in which a portion of the display unit **120** overlaps with a portion of the testing wire **150**, the half cutting crosses the portion of the testing wire **150**. In some embodiments, the testing wire **150** may be formed in an outer region of the half cutting line **163**, which is outside a region in which the TFE unit **130** is formed, since the wire region **140** has a small width, and if the width of the wire region **140** is further decreased, an electrical characteristic deteriorates, resulting in an increase of resistance of the testing wire **150**, and thus, the portion of the testing wire **150** overlaps the half cutting line **163**.

The full cutting is performed along the full cutting line **164** formed in the wire region **140**. In some embodiments, the full cutting is performed in a manner that a cutting tool cuts the array substrate **100** in a thickness direction from a top surface of the testing wire **150** to a bottom surface of the second lower protective film **160**.

As described above, in some embodiments of a cutting process, the half cutting is performed on the array substrate **100** in the thickness direction from the top surface of the display unit **120** to the bottom surface of the first lower protective film **110**, and the full cutting is performed so that the array substrate **100** is completely cut in the thickness direction to the bottom surface of the second lower protective film **160**.

In some embodiments, after the half cutting and the full cutting are performed, a remaining part **310** that is on the second lower protective film **160** and that corresponds to a region between the half cutting line **163** and the full cutting line **164** is removed. Since a bottom surface of the remaining part **310** is attached to the second lower protective film **160** by using the adhesion layer **170** having low adhesion, the remaining part **310** may be easily removed.

In some embodiments, after the remaining part **310** is removed, as illustrated in FIG. **3**C, a top surface **161** of the second lower protective film **160** is exposed at an outer region of the half cutting line **163**.

Next, after the second lower protective film **160** that is attached to the first lower protective film **110** by using the adhesion layer **170** is removed, as illustrated in FIG. **3**D, the individual display unit **120** that is covered by the TFE unit **130** is formed on the first lower protective film **110** corresponding to the mother substrate **110**.

FIGS. **4**A through **4**D illustrate a process of forming individual display units, according to another embodiment of the present invention. FIG. **4**A is a cross-sectional perspective view illustrating a state in which an upper protective film **460** is formed on a mother substrate, FIG. **4**B is a cross-sectional perspective view illustrating a state in which half cutting and full cutting are performed on the mother substrate of FIG. **4**A, FIG. **4**C is a cross-sectional perspective view illustrating a state in which a remaining part **500** on the mother substrate of FIG. **4**B is removed, and FIG. **4**D is a cross-sectional perspective view illustrating a state in which the upper protective film **460** arranged on the mother substrate of FIG. **4**C is removed.

Here, an array substrate **400** for a flexible display device has been first cut in one direction of the array substrate **400**, and then is to be cut in another direction so as to be divided into individual display units.

First, as illustrated in FIG. **4**A, the array substrate **400** for a flexible display device is arranged.

The array substrate **400** includes a lower protective film **410** and the upper protective film **460**. The upper protective film **460** includes a first upper protective film **470** and a second upper protective film **490**. In some embodiments, the lower protective film **410**, the first upper protective film **470**, and the second upper protective film **490** are formed of a flexible material, such as polymer resin.

In some embodiments, the lower protective film **410** functions as a mother substrate having a size by which a plurality of display units **420** may be simultaneously manufactured.

The display units **420** are arrayed in one direction on a top surface of the lower protective film **410**. Each of the display units **420** includes a display region **421** and a non-display region **422** that extends from the display region **421** to an edge of the display unit **420**. The display region **421** is covered by a TFE unit **430**.

A wire region **440** is formed between a pair of adjacent display units **420**. A testing wire **450** having a stripe shape is patterned in the wire region **440**. At least one testing wire **450** is formed in one direction of the array substrate **400**.

Although not illustrated, a semiconductor active layer, a gate electrode, source and drain electrodes, and an insulating layer to insulate them from each other are formed in the display region **421**, and one or more insulating layers that correspond to the insulating layer are stacked in the non-display region **422** and in the wire region **440** so as to insulate devices in the display region **421**. Also, it may be preferable in the manufacturing method that the testing wire **450** is formed together with the gate electrode or the source and drain electrodes on the one or more insulating layers when the gate electrode or the source and drain electrodes are formed.

In some embodiments, the first upper protective film **470** is formed on the display unit **420** that is covered by the TFE unit **430**, to decrease damage to the display unit **420** in a cutting process.

The second upper protective film **490** is attached to a top surface of the first upper protective film **470**. In some embodiments, the second upper protective film **490** may be attached to the top surface of the first upper protective film **470** by using an adhesion layer **480**. In some embodiments, the adhesion layer **480** may be formed of a material having low adhesion so as to facilitate easy detachment of the display units **420**. Although not illustrated, an adhesion layer may be formed on a bottom surface of the first upper protective film **470** so as to allow separation between the first upper protective film **470** and the display unit **420** that is covered by the TFE unit **430**.

In some embodiments, the adhesion layer **480** may be separately arranged, and then may be interposed between the first upper protective film **470** and the second upper protective film **490** or may be coated in a liquid state on at least one of the top surface of the first upper protective film **470** and a bottom surface of the second upper protective film **490** of FIG. **4**A.

In order to individually divide the display units **420**, a cutting line **462** is formed on the lower protective film **410**. The cutting line **462** includes a half cutting line **463** that is formed along an edge of the display unit **420** so as to separate the display unit **420**, and a full cutting line **464** that is arranged in the wire region **440** between a pair of adjacent display units **420**. The half cutting line **463** corresponds to the edge of the display unit **420**.

After the array substrate **400** is formed, as illustrated in FIG. **4**B, by performing half cutting and full cutting on the lower protective film **410**, the display units **420** are individually divided. For convenience of description, in some embodiments, the lower protective film **410** may be positioned at a lower side of FIG. **4**B, but in the actual cutting process, it is preferable that the lower protective film **410** is positioned at an upper side of FIG. **4**B by turning the array substrate **400** upside down.

The half cutting is performed along the half cutting line **463** that is formed along the edge of the display unit **420**. In some embodiments, the half cutting is performed in a manner that a cutting tool cuts the array substrate **400** in a thickness direction from the top surface of the lower protective film **410** to a top surface of first upper protective film **470**. The first upper protective film **470** and the second upper protective film **490** are not cut.

Here, since the half cutting line **463** overlaps with a portion of the testing wire **450**, the half cutting crosses the portion of the testing wire **450**.

The full cutting is performed along the full cutting line **464** formed in the wire region **440**. In some embodiments, the full cutting is performed in a manner that a cutting tool cuts the array substrate **400** in a thickness direction from the top surface of the lower protective film **410** to a bottom surface of the second upper protective film **490**.

As described above, in some embodiments of the cutting process, the half cutting is performed on the array substrate **400** in the thickness direction from the top surface of the lower protective film **410** to the top surface of the first upper protective film **470**, and the full cutting is performed so that the array substrate **400** is completely cut in the thickness direction to the bottom surface of the second upper protective film **490**.

After the half cutting and the full cutting are performed, is some embodiments the remaining part **500** that is on the first upper protective film **470** and that corresponds to a region between the half cutting line **463** and the full cutting line **464** is removed. Since a bottom surface of the remaining part **500** is attached to the first upper protective film **470** by using an adhesion layer (not shown) that is weak to a mechanical contact or that has low adhesion, the remaining part **500** may be easily removed.

After the remaining part **500** is removed, as illustrated in FIG. **4**C, a top surface **471** of the first upper protective film **470** is exposed at an outer region of the half cutting line **463**.

Next, in some embodiments the second upper protective film **490** that is attached to the first upper protective film **470** by using the adhesion layer **480** may be removed in a following process, such as an auto view test (AVT), and the second upper protective film **490** is removed in a following process for attachment of a polarizing plate. Then, as illustrated in FIG. **4**D, the individual display unit **420** that is covered by the TFE unit **430** is formed on the lower protective film **410** corresponding to the mother substrate.

As described above, some embodiments provide an array substrate for a flexible display device and the method of manufacturing the array substrate, the lower protective film configured as the mother substrate is formed of a plurality of films, and a cutting process is performed by using half cutting and full cutting, so that a contact between the array substrate and equipment or a worker may be maximally decreased. Accordingly, it is possible to prevent propagation of an edge crack.

Also, since the upper protective film that is on the display units arrayed on the mother substrate may be formed of a plurality of films, and a cutting process is performed by using half cutting and full cutting, it is possible to minimize propagation of an edge crack.

While the present embodiments have been particularly shown and described with reference to exemplary embodiments thereof, it will be understood by those of ordinary skill in the art that various changes in form and details may be made therein without departing from the spirit and scope of the present embodiments as defined by the following claims.

What is claimed is:

1. A method of manufacturing an array substrate for a flexible display device, the method comprising:

arranging at least one lower protective film, wherein a plurality of display units that are covered by thin-film encapsulation (TFE) units are arrayed on the at least one lower protective film;

performing half cutting and full cutting on the at least one lower protective film to provide remaining parts on the at least one lower protective film; and

removing the remaining parts on the at least one lower protective film from the half cutting and full cutting.

2. The method of claim **1**, wherein the arranging of the at least one lower protective film comprises arranging a first lower protective film on which the plurality of display units are arrayed and a second lower protective film that is attached to the first lower protective film by using an adhesion layer.

3. The method of claim **2**, further comprising:

arraying the plurality of display units at regular intervals on the first lower protective film, wherein each of the plurality of display units comprises a display region and a non-display region; and forming a plurality of testing wires in a wire region between adjacent display units of the plurality of display units, wherein the plurality of testing wires are electrically connected to the adjacent display units, respectively.

4. The method of claim **3**, wherein the performing of the half cutting and full cutting comprises:

performing the half cutting along a half cutting line whereby the plurality of display units are individually divided along edges of the plurality of display units; and

performing the full cutting along a full cutting line in the wire region between the adjacent display units.

5. The method of claim **4**, wherein:

the half cutting is performed from a top surface of each of the plurality of display units to a bottom surface of the first lower protective film in a half-cut region, and

the full cutting is performed from a top of the plurality of testing wires to a bottom surface of the second lower protective film in a full-cut region.

6. The method of claim **5**, wherein:

the full cutting line overlaps with the plurality of testing wires, and

the half cutting line crosses a portion of the plurality of testing wires.

7. The method of claim **5**, wherein, after the half cutting and full cutting are performed, a remaining part on the second lower protective film in a region between the half-cut region and the full-cut region is removed.

8. The method of claim **7**, wherein the second lower protective film is detached from the first lower protective film whereby each of the plurality of display units is completely manufactured.

9. The method of claim **2**, wherein the first lower protective film and the second lower protective film comprise a flexible material.

10. The method of claim **1**, further comprising arranging a first upper protective film that is arranged on a top surface of the plurality of display units in an opposite direction to the at least one lower protective film, and a second upper protective film that is attached to the first upper protective film by using an adhesion layer.

11. The method of claim **10**, further comprising:

arraying the plurality of display units at regular intervals on the at least one lower protective film, wherein each of the plurality of display units comprises a display region and a non-display region;

forming a plurality of testing wires in a wire region between adjacent display units of the plurality of display units, wherein the plurality of testing wires are electrically connected to the adjacent display units, respectively;

attaching the first upper protective film to the top surface of the plurality of display units covered by the TFE units; and

attaching the second upper protective film to a top surface of the first upper protective film.

12. The method of claim **11**, wherein the performing of the half cutting and full cutting comprises:

performing the half cutting along a half cutting line whereby the plurality of display units are individually divided along edges of the plurality of display units in a half-cut region; and

performing the full cutting along a full cutting line in the wire region between the adjacent display units in a full-cut region.

13. The method of claim **12**, wherein:

the half cutting is performed from a top surface of the at least one lower protective film to the top surface of the first upper protective film, and

the full cutting is performed from the top surface of the at least one lower protective film to a bottom surface of the second upper protective film.

14. The method of claim **13**, wherein:

the full cutting line overlaps with the plurality of testing wires, and

the half cutting line crosses a portion of the plurality of testing wires.

15. The method of claim **13**, further comprising removing a remaining part on the first upper protective film, in a region between the half-cut region and the full-cut region.

16. The method of claim **15**, wherein the second upper protective film is detached from the first upper protective film whereby each of the plurality of display units is completely manufactured.

17. The method of claim **11**, wherein the first upper protective film, the second upper protective film, and the at least one lower protective film comprise a flexible material.

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